PRODUCTION OF ETHANOL AND VEGETABLE PROTEIN BY GRAIN FERMENTATION

Wm. A. Scheller and Brian J. Mohr

Department of Chemical Engineering, University of Nebraska
Lincoln, Nebraska 68508

INTRODUCTION

Since the end of World War II the use of synthetic ethanol for industrial purposes in the United States has grown at a steady pace displacing ethanol produced by the fermentation of grain and molasses. In 1970 less than 5% of the U.S. industrial ethanol was produced by fermentation. Because of FDA regulations that require ethanol for human consumption be produced by the fermentation of grain, fruit or sugar, the synthetic ethanol industry has not penetrated the beverage market. In 1972 approximately 37 million bushels of grain were fermented to produce 94.2 million gallons of ethanol expressed as 200°proof (100%) alcohol. During the same year approximately 241 million gallons of ethanol (as 200°proof) were produced synthetically from ethylene and ethyl sulfate. The bulk of the ethanol consumed by industry outside of the United States is produced by fermentation of fruit, grain, and molasses. In 1972, 800 million gallons of fermentation ethanol (as 200°proof) were consumed by industry outside of the U.S.A.

Synthetic ethanol has had a very stable price history. Between 1959 and 1969 the price was 52¢/gallon for 190°proof alcohol. In 1970 the price increased to 54¢/gallon and remained there into 1973. 200°proof synthetic ethanol typically costs 7¢/gallon more than 190°proof. These prices are quoted without the federal beverage alcohol tax.

The dramatic increase in the price of energy which came about in late 1973 has caused the price of ethylene to increase sharply. This in turn has caused a substantial price increase for synthetic ethyl alcohol. An estimate of the 1974 price for synthetic ethanol is shown in Table I. The increase in fuel prices added 10.3¢/gallon to the alcohol cost and the increase in the price of ethylene has added another 28.7¢/gallon to the cost bringing the 1974 price to $1/gallon. Actual quotations on tank car prices of synthetic ethanol have been difficult to obtain. Two major producers of synthetic ethanol, Exxon Corporation and Tennessee Eastman, have announced that their synthetic ethanol plants would be shut down at the end of 1974. These plants represent about 22% of the U.S. synthetic ethanol production capacity.

The price of ethanol produced by fermentation in the beverage trade is not generally available. A rough estimate can be made if we consider that a fifth of 80°proof vodka sells for as little as $2.79 including the federal alcohol tax. If one deducts the taxes and, recognizing that vodka is only a 40% blend of ethanol and water, corrects the price to pure ethanol he obtains about $10/gallon. Recognizing that bottling, packaging, shipping and distribution expenses are signficant, it might be reasonable to assume that the fermentation ethanol as 200°proof alcohol is worth at least $1/gallon in the distillery storage tanks. This is comparable to the current price estimated for synthetic ethanol.

Because ethanol produced by both processes is chemically equivalent and now cost the same, fermentation ethanol need no longer be limited to the beverage market. Furthermore, with the potential for recovering a valuable protein concentrate from the by-products of fermentation alcohol manufacture it now appears that fermentation ethanol can actually become cheaper than synthetic ethanol. With increasing fuel prices and increased world demand for protein sources fermentation ethanol may have the potential for being produced at a price based on its fuel properties which will make it attractive as a blending component in automotive fuel.

PRODUCTION OF ETHANOL BY GRAIN FERMENTATION

The process for the production of ethanol by the fermentation of grain is well established. Starch containing grains such as wheat, corn, milo, etc. are ground to expose the interior of the kernel and cooked to gelantinize the natural starches. The cooked grain is cooled and an enzyme is added to convert the starch to sugar. The sugars are then fermented to ethanol anaerobically with yeast and the alcohol recovered from the mixture by fractional distillation.

Two by-products result from this fermentation process, carbon dioxide and distillers dried grains with solubles. The distillers dried grains represent the insoluble materials in the original grain such as fiber, ash, and protein. The soluble components such as unconverted starch and soluble proteins are concentrated and dried with the distillers dried grains to yield this by-product. The distillers dried grains plus solubles (DDG&S) are a desirable high protein content (25-30%) cattle feed. In 1972 slightly more than 400 thousand tons of DDG&S were produced and in 1973 their average selling price was $117/ton. The carbon dioxide produced is of high purity and if a market is available this gas can be sold at $2/ton or more at atmospheric pressure.

The cost of converting grain into 200°proof ethanol is about 28.6¢/gallon of alcohol. This cost includes utilities, labor, supervision, maintenance, etc. but does not include the cost of the grain nor depreciation. The investment for an alcohol plant to produce 20 million gallons/year of 200°proof ethanol from milo (a feed grain belonging to the corn family) is approximately $18 million. Milo contains about 70% starch and a typical price that agricultural economists estimate in the next 12 months is $2.29/bushel at a moisture content of 15.5 weight per cent. The process would also produce 174 tons/day of carbon dioxide and about 218 tons/day of DDG&S at a 14% moisture content.

Table III shows an economic evaluation for the production of 20 million gallons/year of 200°proof ethanol from 21,490 Bu/day of milo. With ethanol valued at $1/gallon and distillers dried grains at $120/ton, the total annual income from such a plant if $29.68 million. The expenses for such a plant include the cost of milo, and the conversion cost. These total $23.68 million per year. This then gives a profit of $6 million/year before depreciation and taxes which in turn gives a payout of 3 years for the investment of $18 million.

RECOVERY OF PROTEIN FROM DDG&S

As mentioned above, the DDG&S contains between 25% and 30% protein depending on the protein content of the original grain. A portion of this protein may be soluablized by treating the DDG&S with a pH greater than 11.0. If the pH is then lowered to about 4.0 a sizable portion of the protein will precipitate. The process equipment requirements are not complex. The amino acid profile of the protein concentrate depends to a great extent on that of the original grain.

Table III contains an economic evaluation for a process to produce 20 million gallons/year of 200°proof ethanol and to recover 66,200 lb/day of protein concentrate (85% protein) from the distillers dried grains and solubles. In this case the value of the DDG&S is reduced to $90/ton after the protein has been removed. The protein concentrate has been estimated by an agricultural economist to have a value in the human food market of about 60¢/lb. The incremental investment for the protein plant is $4 million and the conversion cost for recovery of the protein is $1.09 million per year. The value placed on ethanol in this case is that which will provide a three year payout on the total investment for the alcohol plant plus the protein plant i.e. a profit of $7,370,000/year. From the figures shown in Table III it can be seen that the 20 million gallons per year of ethanol must bring an income of $11,600,000/year or 58¢/gallon.

ETHANOL IN GASOLINE

As a component in gasoline anhydrous ethanol has a blending octane number of 123. If the differential value between 94 octane regular gasoline and 100 octane supreme gasoline is 2¢/gallon at the wholesale level then ethanol as a blending component in gasoline is worth 9.7¢/gallon more than the price of 94 octane regular. This in turn means that when the wholesale price of regular gasoline excluding state and federal taxes is 48.3¢/gallon ethanol at 58¢ per gallon can be used as an economical blending component based on its fuel properties. Allowing for a 35¢ mark-up to retail price and adding 12.5¢/gallon state and federal taxes we come to a retail price of 77.7¢/gallon of gasoline at the pump as being consistent with an alcohol price of 58¢/gallon at the distillery. Table II is a comparison of price (including taxes) of 94 O.N. regular gasoline at the pump with the alcohol price at the distillery which is necessary for anhydrous ethanol to be an economical gasoline blending component.

CONCLUSIONS

Based on laboratory studies it has been shown that protein of a quality suitable for human consumption can be extracted from vegetable materials such as distillers dried grains and solubles, the by-product of the production of ethanol by grain fermentation. Economic evaluations of the investment and operating cost requirements for the production of anhydrous ethanol from grain and the recovery of protein concentrate from distillers dried grains and solubles indicates that the protein recovery can reduce the selling price of alcohol without adversely affecting the return on investment. In the case where milo was used as the feed grain to the fermentation process the selling price of anhydrous ethanol could be reduced from $1/gallon to 58¢/gal. while maintaining a 3 year payout on investment. If ethanol were available at 58¢/gallon it would be economical to use as a blending component in gasoline if the price of regular gasoline at the pump including state and federal taxes were 77.7¢/gallon. Lower grain prices would permit lower ethanol costs which in turn would make the ethanol attractive at lower gasoline prices. Recovery of the protein concentrate from the distillers dried grains results in an increase of about 46% in the total amount of protein produced over feeding the grain directly to cattle. The energy deficit associated with farming and fermentation ethanol production has been shown elsewhere to be less than that associated with ethanol production from light gases via ethylene.

Table I

Current Price Estimate For Synthetic Ethanol

Base Price in 1972	61.0¢/gal
Increase in Fuel Prices of 90¢/million Btu	10.3
Increase in Ethylene Price from 3¢/lb to 10¢/lb	28.7
1974 Price	$1.00/gal

Table II

Value of Ethanol as a Gasoline Component

Gasoline 94 O.N. Reg. (Incl. Tax)	Ethanol Value at the Distillery
52¢/gal	39.0¢/gal
60	44.9
80	59.7
100	74.5

Table III

Economic Evaluation for the Production
of 20 Million Gallons per year of 200°Proof Ethanol

			Without Protein Recovery		With Protein Recovery
Feed:	Milo (Bu/Day)		21,490		21,490
Products:	Ethanol (Gal/yr)		20,000,000		20,000,000
	Distillers Dried Grains & Solubles (Ton/Day)		218		180
	Carbon Dioxide (Ton/Day)		174		174
	Protein (Lb/Day)		---		66,200
Income:	Ethanol	@ $1/gal	$20,000,000/yr	@ 58¢/gal	$11,600,000/yr
	DDG&S	@ $120/ton	9,550,000	@ $90/ton	5,910,000
	CO_2	@ $2/ton	130,000	@ $2/ton	130,000
	Protein		---	@ 60¢/lb	14,500,000
	Total Income		$29,680,000		$32,140,000
Expenses:	Milo	@ $2.29/Bu	$17,960,000/yr		$17,960,000/yr
	Conversion Cost		5,720,000		6,810,000
	Total Expenses		$23,680,000		$24,770,000
Profit:	Before Taxes and Depreciation		$ 6,000,000/yr		$ 7,370,000/yr
Capital Investment:			$18,000,000		$22,000,000
Payout:	Before Taxes and Depreciation		3.0 yrs		3.0 yrs